Top

X-HALE

Designing the Atmospheric Surveillance Platforms of the Future

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Imagine the benefits that battlefield commanders or intelligence analysts could derive from an airborne surveillance platform that would carry a 500-pound payload, operate above the range of small-arms fire, remain on station for weeks or even years, cost much less than a satellite, and relocate around the globe to a new region of interest within a couple of weeks. Realizing this concept, known as a high-altitude, long-endurance (HALE) aircraft, is a 10-to-15-year goal of researchers at the Air Force Institute of Technology (AFIT). In order to reach this goal, those researchers are following a developmental path similar to the one the Wright brothers used over a century ago by gathering new test data and building theoretical formulations for this aircraft. The brothers' discovery that the existing aeronautical data of the day was inaccurate proved key to their success. Indeed, Wilbur Wright even wrote that "having set out with absolute faith in the existing scientific data, we were driven to doubt one thing after another, until finally, after two years of experiment, we cast it all aside, and decided to rely entirely upon our own investigations."[1]

The air and space community experienced a dramatic reminder of the importance of developing accurate aerodynamic data and computer software on 26 June 2003. On that date, the National Aeronautics and Space Administration's (NASA) Helios aircraft, a uniquely flexible HALE design intended to cruise up to an altitude of 100,000 feet, became unstable during a test flight and crashed due to excessive wing deformation, followed by uncontrolled flight and catastrophic failure of upper-wing surfaces. Accident investigators concluded that the root cause of the accident was a "lack of adequate [aerodynamic] analysis methods [which] led to an inaccurate risk assessment of the effects of configuration changes leading to an inappropriate decision to fly an aircraft."[2] Even though modern fifth-generation fighter aircraft are designed with state-of-the-art aeronautical tools, the latter fail at designing very flexible HALE aircraft that fly at less than 80 miles per hour. Furthermore current tools fail to predict the stability and control of these aircraft.

The Helios accident highlighted the limitations of our understanding and of the analytical tools (computer software) necessary for designing HALE aircraft such as the Helios, which have the potential to offer immunity from most ground threats while providing low-cost surveillance. Following the Helios accident, NASA's primary recommendation called for the development of "more advanced, multidisciplinary (structures, aeroelastic, aerodynamics, atmospheric, materials, propulsion, controls, etc.) '*time-domain*' analysis *methods* appropriate to highly flexible, 'morphing' vehicles" (emphasis in original).[3]

Despite the lack of fundamental aerodynamic knowledge and analytical tools

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(particularly computer software) necessary to understand the aerodynamic behavior of these vehicles, aircraft designers are still striving to develop aircraft that incorporate the latest sensor technology. However, most of these designs continue to have critical constraints in the areas of mission duration, the payload's electrical power supply, and payload weight. To fully exploit the potential of sensor technology, we need a long-term surveillance platform.

Researchers at AFIT have been collaborating with the Defense Advanced Research Projects Agency (DARPA) since 2008 to develop a HALE aircraft capable of remaining airborne continuously for five years. The Vulture program has the potential to combine the best aspects of aircraft station keeping and low-cost relocation with the persistence and high-ground advantage of a satellite system.

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Due to mission requirements, HALE aircraft are characterized by high-aspect-ratio wings and slender fuselages, resulting in very flexible vehicles. These geometric constraints make the aircraft susceptible to large, dynamic wing deformations at low frequencies. Such deformations can adversely affect the vehicle's flight characteristics, as demonstrated during the Helios flight tests.[4] Despite that accident, development of DARPA's Vulture program, developmental designs of other civilian HALE aircraft, and recent analytical work reveal a severe shortage of experimental test data.[5] These data are critical to further advance an understanding of the flight dynamics and control of HALE aircraft and to validate recent progress in software and aerodynamics.[6]

An Experimental High-Altitude, Long-Endurance Aircraft

AFIT began a research effort in 2007 to locate existing, available data for validating the software and aerodynamic theory for HALE aircraft. That effort ended when a DARPA-sponsored meeting of experts from academe, the Department of Defense (including the author), NASA, and industry confirmed the suspicion that no complete set of available data existed for such validation research.[7] Interestingly enough, NASA's Helios aircraft could have supplied this information had political and programmatic obstacles not prevented installing instruments on the aircraft to collect it.

Because of the lack of available data, AFIT began a second research effort, utilizing the unique expertise of researchers at the University of Michigan. On 27 August 2008, AFIT formed a partnership with the university's Aerospace Engineering Department to develop an experimental high-altitude, long-endurance (X-HALE) remotely piloted aircraft supported by the Air Force Research Laboratory's (AFRL) Air Vehicles Directorate and directed by AFIT. The partnership has designed a HALE aircraft using tools developed by AFIT, AFRL, and the University of Michigan, producing two

different design configurations (see figure) with certain design characteristics (see table). If the response to tests of the aircraft's initial configuration (having a six-meter wingspan) does not provide the requisite flight dynamic features (coupled wing flexibility with aircraft lateral and longitudinal control), then testing will move to the eight-meter concept.[8]

The first X-HALE flight test is scheduled for late spring or summer 2011 at Camp Atterbury, Indiana. For these tests, the University of Michigan will provide expertise in handling the aircraft; AFIT, flight-test expertise and program management; and AFRL, funding and program oversight. The tests seek to validate HALE aircraft design tools by employing accumulated flight-test data to build and fly the X-HALEs successfully. For the first of two series of X-HALE flight tests, the aircraft will carry a limited set of instrumentation to reduce programmatic risk. Upon successful completion of this series of tests, researchers will build a second vehicle with more extensive instrumenta-

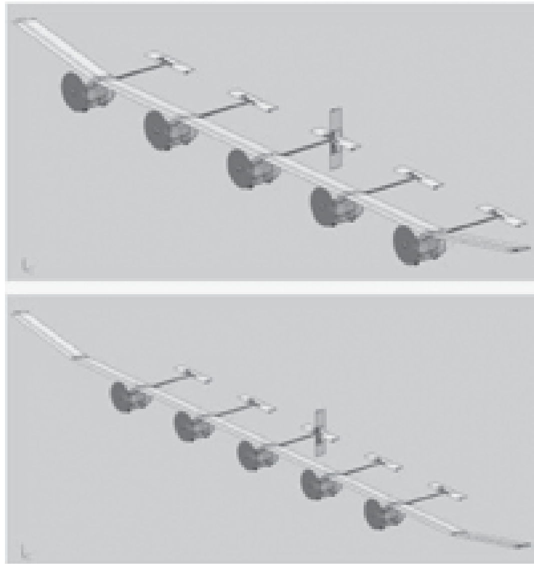

Figure. X-HALE six- (above) and eight-meter (below) wingspan designs

Table. Characteristics of X-HALE remotely piloted aircraft

Wingspan	6 meters (m) or 8 m
Chord	0.2 m
Planform Area	1.2 square meters (m^2) or 1.6 m^2
Aspect Ratio	30 or 40
Length	0.96 m
Propeller Diameter	0.3 m
Gross Takeoff Weight	11 or 12 kilograms (kg)
Power/Weight	30 watts/kg
Airspeed	12–18 m/second
Maximum Range	3 kilometers
Endurance	45 minutes

tion and flight-test objectives to meet the primary research goal of collecting flight-test data to validate the HALE aircraft's research software and aerodynamic theory. The researchers plan to share all data with several large air and space companies that have followed this project with great interest.

Conclusion

The Air Force's goal of achieving persistent aerial surveillance has long represented the holy grail of the intelligence community. Researchers have made great strides in developing aircraft platforms and sensors, but the proliferation of asymmetric warfare means that the United States desperately needs aircraft that can loiter over a target of interest for weeks or years. AFIT's researchers, along with its strategic partners, are making great progress in offering these tools to the war fighter. Currently, the way forward involves combining the high ground of satellites with the navigational flexibility of aircraft. The X-HALE program will supply the test data and the validated design tools that AFIT and industry researchers need to design an aircraft to meet our war fighters' need for persistent aerial surveillance. ✪

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Notes

1. John D. Anderson Jr., *Introduction to Flight*, 3rd ed. (New York: McGraw-Hill, 1989), 29.

2. Thomas E. Noll et al., *Investigation of the Helios Prototype Aircraft Mishap*, vol. 1, *Mishap Report* (Washington, DC: Headquarters NASA, January 2004), 10, http://www.nasa.gov/pdf/64317main_helios.pdf.

3. Ibid.

4. Ibid., 9.

5. Christopher M. Shearer and Carlos E. S. Cesnik, "Nonlinear Flight Dynamics of Very Flexible Aircraft" (presentation AIAA-2005-5805, AIAA [American Institute of Aeronautics and Astronautics] Atmospheric Flight Mechanics Conference and Exhibit, San Francisco, 15–18 August 2005), http://deepblue.lib.umich.edu/bitstream/2027.42/76937/1/AIAA-2005-5805-748.pdf; and Shearer and Cesnik, "Trajectory Control for Very Flexible Aircraft" (presentation AIAA-2006-6316, AIAA Guidance, Navigation, and Control Conference and Exhibit, Keystone, CO, 21–24 August 2006), http://deepblue.lib.umich.edu/bitstream/2027.42/77218/1/AIAA-2006-6316-117.pdf.

6. Technical sources include Christopher M. Shearer, "Coupled Nonlinear Flight Dynamics, Aeroelasticity, and Control of Very Flexible Aircraft" (PhD diss., University of Michigan, 2006); Rafael Palacios and Carlos E. S. Cesnik, "Static Nonlinear Aeroelasticity of Flexible Slender Wings in Compressible Flow" (presentation AIAA-2005-1945, 46th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Austin, TX, 18–21 April 2005), http://deepblue.lib.umich.edu/bitstream/2027.42/76231/1/AIAA-2005-1945-496.pdf; Leonard Meirovitch and Ilhan Tuzcu, "Unified Theory for the Dynamics and Control of Maneuvering Flexible Aircraft," *AIAA Journal* 42, no. 4 (April 2004): 714–27; Mayuresh J. Patil, Dewey H. Hodges, and Carlos E. S. Cesnik, "Nonlinear Aeroelastic Anaylsis of Complete Aircraft in Subsonic Flow," *Journal of Aircraft* 37, no. 5 (September–October 2000): 753–60; and Mark Drela, "Integrated Simulation Model for Preliminary Aerodynamic, Structural, and Control-Law Design of Aircraft" (presentation AIAA-99-1394, 40th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit, St. Louis, MO, 12–15 April 1999), http://web.mit.edu/drela/Public/web/aswing/asw_aiaa.pdf.

7. DARPA sponsored a nonlinear aeroelastic tools meeting on 10 and 11 September 2008 in Washington, DC.

8. "Coupled wing flexibility with aircraft lateral and longitudinal control" results from the inherent flexibility of HALE aircraft wings. In response to an aileron or roll input, the outer portion of the wing initially deforms. The movement of the rest of the airplane lags behind this initial movement of the wing. This reaction resembles the way an ocean wave first forms, yet the resulting motion of the water at the shoreline lags behind the initial movement of the wave. The lag in movement of the aircraft due to an aileron input creates additional problems with stability and control. In most aircraft, the wing is so stiff that aileron inputs cause the entire aircraft to begin to roll almost instantly.